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16. ABSTRACT

A test stand for the examination of flow monitors in a 3-inch pipe was designed, constructed, and evaluated. The calculations necessary for the proper design are based on empirical data and are described in detail. A statistical analysis was used to estimate the error generated from various alternative methods of determining flow. Such estimates included errors in weighing, measuring liquid level, and measuring time and errors resulting from diversions of liquid from the main stream to the collection tank. The volume/time method proved not only to have the least error (± 0.75 percent) of the several options that were studied, but also was amenable to monitoring fluids of unknown densities.

The data from the flow test stand which are based on a magnetic flowmeter are traceable to the National Bureau of Standards and are reported to have errors of ± 0.5 percent or less. The techniques used in clarifying traceability to the National Bureau of Standards are described.

The flow test stand has the capability of testing flowmeters using clean water or various types of industrial or municipal wastewater effluents.

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INTRODUCTION

The National Pollutant Discharge Elimination System (NPDES) requires that permits be issued to all dischargers into navigable waters and that the major dischargers be inspected annually. Such an inspection may be a Compliance Sampling Inspection (CSI) in which a sample of the discharge is taken and analyzed. At the same time, the flow is measured so that when the analysis and flow information are combined, mass discharge rates can be calculated for comparison with the permit limitations. In order to assure that the flow readings are accurate, a flow test stand was constructed which has the capability of calibrating flow monitors used in the CSI program. The flow test stand was designed so that flowmeters may be tested in not only clean water but also in various industrial and municipal effluents. With proper pump changes, the flow test stand could be used to test meters which monitor primarily sludge flows.

DESIGN OF THE FLOW TEST STAND

Prior to final construction, various alternative methods for operating the flow test stand were statistically evaluated. The random and bias errors resulting from alternative procedures, such as gravimetric or volumetric measurements with or without level detectors and electronic

timers were determined. The most suitable procedure, volumetric measurements without level detectors but with electronic timers, was utilized. A magnetic flowmeter with an accuracy of ± 0.5% for the range 1-30 ft/sec, as certified by the manufacturer who claims traceability to NBS standards, was included in this study to confirm the information obtained from the flow test stand. The flow test stand was constructed of steel pipe and evaluated over a flow range of 26 to 450 gal/min.

The U. S. Environmental Protection Agency (USEPA) NPDES Compliance Sampling Inspection Manual[1] states that normally a flow error greater than ± 10% is considered unacceptable for NPDES compliance assurance purposes. Furthermore, the accuracy generally accepted as necessary for a proper calibration requires that the accuracy of the reference measurement be 10 times the accuracy of the device under test.[2,3] Recognizing these criteria, the flow test stand must be designed to have an accuracy of ± 1% or better in order to validate flowmeters used in the CSI Program.

Most flow test stands are designed on the principle of the weight/time method for measurement of flow. The weight of the collected water is determined and converted to volume by multiplying by the density which is accurately known for clean water. However, in this case the objective was to use the flow test stand to calibrate flow meters using either clean water or wastewater. In this regard, it seemed more prudent to adopt the volume/time method since densities of wastewaters are variable and not necessarily homogeneous.

Nevertheless, the volume/time and weight/time methods were evaluated using a statistical error analysis in order to select the most suitable technique with an accuracy better than ± 0.75%. In the volume/time approach, two possible alternatives, strip chart recorder or electronic timer, were compared with regard to their accuracies in measuring time. The electronic timer is engaged and disengaged automatically by the divertor valve. Level probes were initially considered to monitor the volume, but were discounted when it was observed that the accuracy of a level measurement was ± 1%.

The potential errors in the use of the flow test stand are described in Appendices A, B, and C where the errors are identified and analyzed statistically. Table 1 summarizes the conclusions of that analysis and presents the single point accuracies at 95% confidence levels.

Table 1

Summaries of Errors

Alternatives for Design	Single Point Accuracy % at 95% Confidence Level
volume/recorder time	± 1.0
volume and electronic timer	± 0.28
weight/time & electronic timer	± 0.26

Table 1 shows that the accuracy for the weight/time method and the volume and electronic timer for flow measurement are similar, but only the volume method has the capability to calibrate flowmeters using wastewaters. Since both clean and wastewater calibration was desired, the volume and electronic timer method was selected.

On the basis of these results the design of the flow test stand was proposed, as illustrated in Figure 1. Water is pumped from the reservoir tank through a control valve and to the magnetic flowmeter. The water is then returned to the reservoir or a measuring tank if a calibration of a flowmeter is desired. Long lengths of straight pipe are used before and after all flowmeters in order to insure flow stability in testing and measuring.

The increased accuracy of the electronic timer required the evaluation of the diversion error which is the error resulting when the water from the reservoir tank is diverted to the measuring tank, as illustrated in Figure 2. The flow of water during diversion may be non-linear as shown in Figure 2 by Area = A_1. Under ideal conditions A_1 should equal A_3. If however, the initial flow (A_1) is larger or smaller because of the inertia of water in switching, a diversion error will result.

The explanation of the collection process below will clarify the resulting error. Two electronic timers were used. One electronic timer measured T_{max} which marked the time the divertor valve first began opening to the time at the end of the measuring cycle when the valve closed again. The second electronic timer measured T_{min} which marked the time the valve

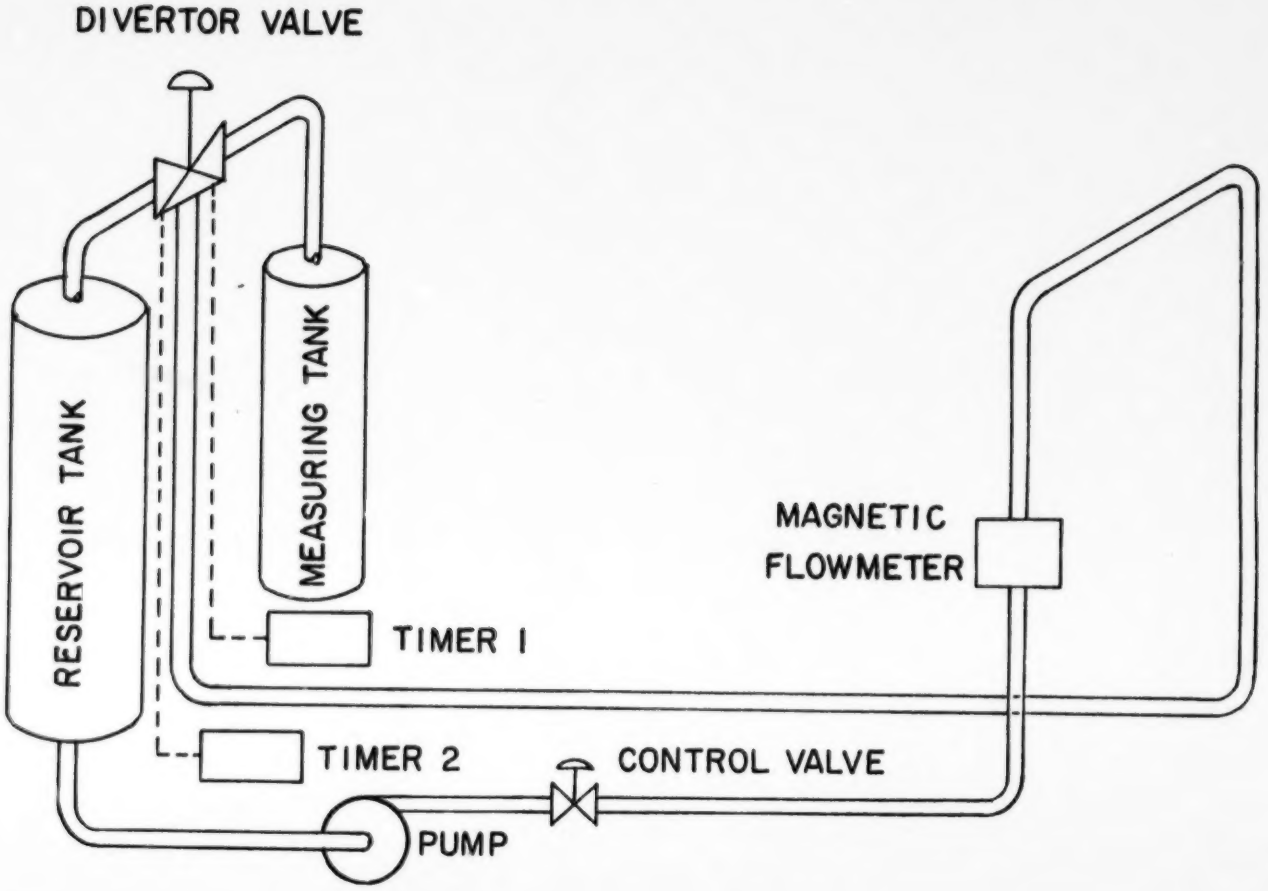

FIGURE 1

SCHEMATIC OF FLOW TEST STAND

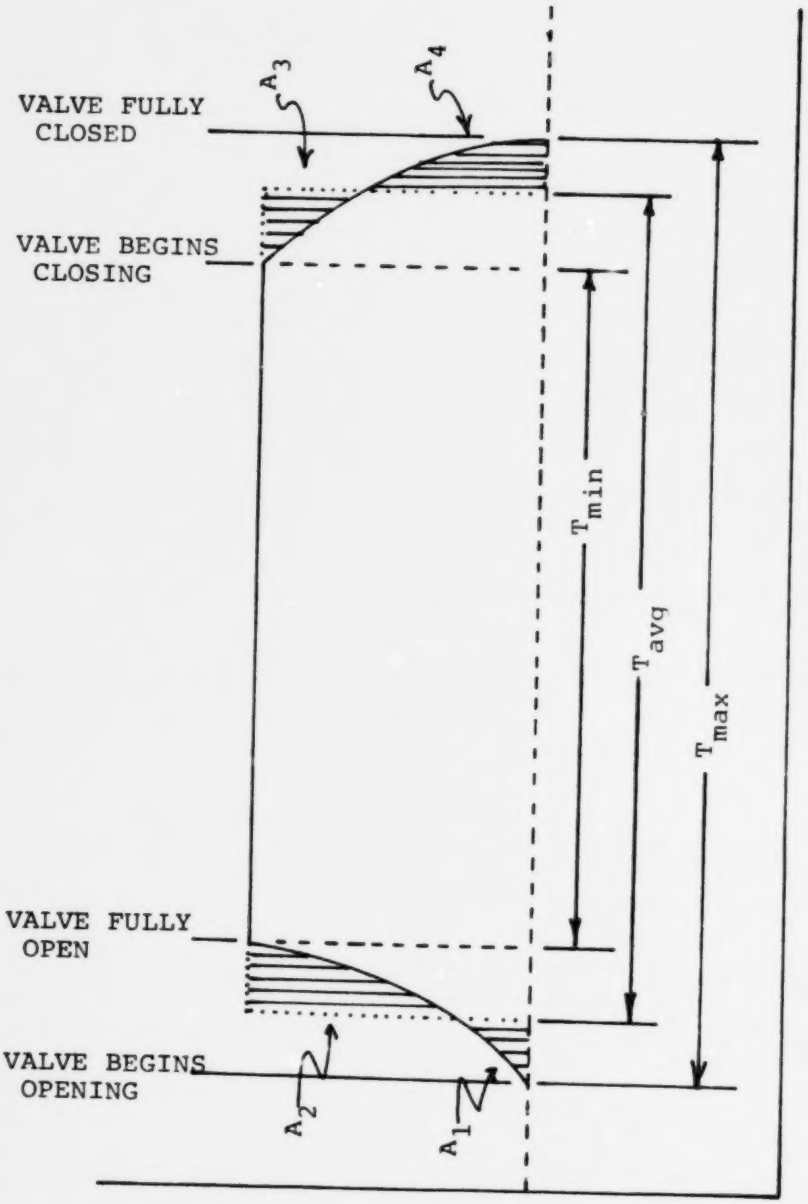

FIGURE 2

GRAPHICAL REPRESENTATION OF DIVERSION

was fully open until the time when the valve first began closing. T_{avg} is defined as the average time of T_{max} and T_{min} and may be used to calculate the flowrate if it can be shown that the areas $A_1=A_3$ and $A_2=A_4$. However, that may not be true as noted above. Therefore, the use of T_{avg}, may result in an error which is called diversion error.

Using the example given by Mattingly,[4] the error resulting from the diversion of the water from the reservoir tank to the measuring tank was calculated by performing two experiments which were conducted at the same flow rate and approximately the same collection time. The first experiment required the measurement of flow by the volume/time method and the magnetic flowmeter over a reasonably long period of time. During this period, the following parameters were determined;

Q_v = Flow rate as measured by the volume/time method during long collection times

Q_m = Magnetic flowmeter reading during the long time collection

In the second experiment the flow was diverted to the collection tank on an on/off basis for as many as ten times. The repetition amplified the diversion error. The following parameters were measured;

q_v = Flow rate as measured by the volume/time method during diversion

q_m = Magnetic meter reading during the diversion

The diversion error is E. T is the total time for the diversion and N is the number of diversions. The equations are derived in Appendix D and the final equation for the diversion error is listed below:

$$E/T = \frac{\frac{Q_v\ q_m}{q_v\ Q_m} - 1}{\frac{NV\ q_m}{V^*\ Q_m} - \frac{Q_v\ q_m}{q_v\ Q_m}}$$

The diversion error was calculated and the results are listed in Table 2.

Table 2
Diversion Errors

N, Number of Diversions	Qm gpm	Qv gpm	V gals	qm gpm	qv gpm	V* gals	Percent Diversion error, E/T %
8	300	304.04	227.19	300	302.03	240.00	0.101
8	300	304.04	227.19	300	304.15	240.00	0.005
8	301	305.40	230.49	300	302.03	252.42	0.124
8	301	305.40	230.49	300	304.15	252.42	0.012
6	445	451.21	231.41	440	444.75	252.85	0.071
6	445	451.21	231.41	440	440.48	248.85	0.285

The diversion error varies from 0.005 to 0.28%, which for the purposes of this flow test stand, allows sufficient accuracy if T_{avg} is used.

A magnetic flowmeter was installed in the test stand to provide a rapid and continuous reading for flow settings, give confirmatory data, and serve as a master working meter. The meter* was selected on the basis of its

*The meter selected was a Brooks Mag 7000. Mention of trade names or products does not constitute an endorsement nor a recommendation by the USEPA.

traceability to the NBS, linearity over the range 1-30 ft/sec., and accuracy of ± 0.5% of 1.00 ft/sec. or ± 0.005 ft/sec. as certified by the manufacturer.

The concept of traceability to NBS may be explained by the use of a pyramid[5] as shown in Figure 3. Each link in the chain does not necessarily have to be followed to develop a traceable NBS calibration program. The amount of standards and equipment needed is a function of the uncertainity in the data that can be tolerated and the type of application. For example, NBS may certify as a transfer standard a Slicker Plate volume which may be regarded as a large volumetric flask or a very accurately calibrated Seraphin Can. Or, NBS may certify the Seraphin Can as a transfer standard, but it may also serve as the working and reference standard. Commonly used working standards are turbine flowmeters and displacement type provers . A second turbine meter to be used to calibrate the process meters may be used as the master meter to prevent wear and tear on the working standard.

Because wastewater may be too abrasive for a quality turbine meter, the magnetic flow meter was used as the master meter for the test stand. The measuring tank in the flow test stand was calibrated using a 5-liter volumetric flask at 20°C.

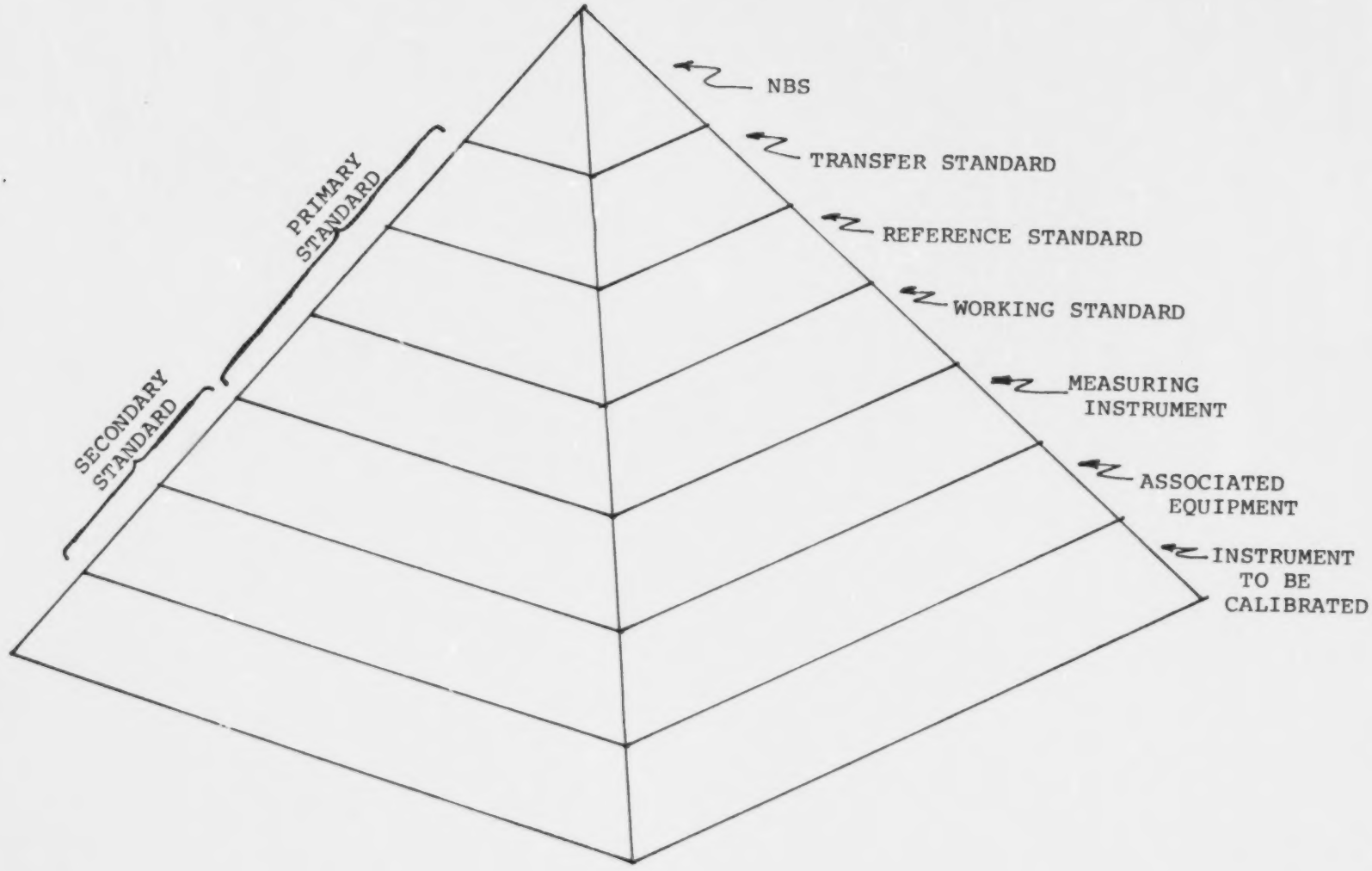

FIGURE 3

CALIBRATION PYRAMID

CONSTRUCTION AND EVALUATION OF THE FLOW TEST STAND

The flow test stand was constructed as illustrated in Figure 1 of STD Schedule 40 steel 3-inch pipe. Four inch pipe was used on the suction end of the pump which was followed by a pressure relief valve allowing the excess water to be returned to the reservoir. The pump was selected based on hydraulic head calculations and NEMA 12 specifications with overload safety protection. Calculations for the headloss are detailed in Appendix E and summarized in Table 3.

Table 3

Headloss Estimates

Straight pipe	Suction Line	9-90° bends	TEE	Control valve	Venturi	Ball valve	Total headloss
46.65	15.8	25.16	3.69	38.39	3	.55	133.24

Based on the headloss and the maximum flow of 600 gal/min, the horsepower of the pump was calculated to be 20. A 25-horsepower pump was installed to provide additional horsepower in the event of a contingency.

Water hammer back pressure waves were reduced by the design of the 3-way divertor valve. This valve consists of two valves. As one opens, the other closes. It was estimated from experimental observations that the temporary change in velocity on switching at 25 ft/sec flow velocity is 1.2 ft/sec with a 0.98 sec switching time. This generates a negligible water hammer back pressure wave.[6]

The test stand was designed to operate in two modes. The first mode is a closed loop in which water from the reservoir tank is pumped through the system and returned to the reservoir with no change in head. In this mode instruments may be inserted into the system and checked using the magnetic flow meter. If further verification is desired, the second mode is implemented. In this mode water from the reservoir is pumped through the system and returned to the measuring tank for a volume/time calibration. The water level in the reservoir is adjusted with make-up water automatically using a level detector and a control system to assure the maintenance of a constant head.

The system was evaluated by comparing the volume/time method with the magnetic flow meter readings. That is, volume/time measurements were repeated several times at flow settings which were determined by the magnetic flow meter. The mean and standard deviation for the volume/time measurements were calculated as listed in Table 4 along with the flow readings from the magnetic flow meter. The percent uncertainty of a reading, given in the last column of Table 4, is defined as the standard deviation, s, times the Student's t at a 95% confidence level and m degrees of freedom, divided by the mean $\overline{X}$;

$$\% \text{ uncertainty} = \frac{s \; t_{m,0.025} \times 100\%}{\overline{X}}$$

The percent uncertainty is a function of the imprecision in both the volume/time and the magnetic flow meter. Each data set was obtained by maintaining a constant flow using the magnetic flowmeter as a reference and collecting the water for a volume/time measurement. Consequently, only the

Table 4
Volume/Time Measurements

Data Set		Magnetic Meter, gal/min.	Volume/time Measurement gal/min.	Mean	Standard Deviation	% Uncertainty
A	1	445	448.09			
	2	445	447.67			
	3	445	448.18			
	4	445	447.65			
	5	445	446.30			
	6	445	445.39	447.21	1.12	0.64
B	1	400	399.24			
	2	400	398.80			
	3	400	399.22			
	4	400	397.57	398.71	0.78	0.62
C	1	300	303.94			
	2	300	303.19			
	3	300	300.84			
	4	300	302.73			
	5	300	301.83			
	6	300	301.77			
	7	300	301.09			
	8	300	301.30			
	9	300	302.46			
	10	300	302.27			
	11	300	301.32			
	12	300	300.84	301.96	0.98	0.73
D	1	250	252.40			
	2	250	251.81			
	3	250	250.32			
	4	250	250.04			
	5	250	249.90			
	6	250	251.13	250.93	1.02	1.05
E	1	200	199.45			
	2	200	200.61			
	3	200	200.19			
	4	200	200.40			
	5	200	199.96	200.12	0.45	0.63
F	1	100	100.67			
	2	100	99.56			
	3	100	98.92			
	4	100	100.75			
	5	100	100.99			
	6	100	100.49			
	7	100	100.23			
	8	100	100.19	100.22	0.68	1.61
G	1	30	29.51			
	2	30	30.97			
	3	30	31.15			
	4	30	30.14			
	5	30	30.45			
	6	30	29.52	30.29	0.70	5.93

volume/time measurements varied, and the percent uncertainties ranged from 0.62 to 5.93%. At the higher flows the percent uncertainty varied from 0.62 to 1.61%. However, at the low flow settings of 30 gal/min, the uncertainty abruptly increased. Further examination revealed a defect in the magnetic flow meter at that range and the meter was returned to the factory for recalibration.

After the meter was recalibrated, the low flow measurements were repeated and the results are listed in Table 5. The results showed a significant improvement at the low ranges where the percent uncertainties varied from 0.14 to 0.86%.

Table 5

Low Flow Volume/Time Measurements

Data Set	Magnetic Meter gal/min.	Volume/time Measurement gal/min.	Mean	Standard Deviation	% Uncertainty
H1	200	199.62	199.69	0.102	0.14
2	200	199.81			
3	200	199.58			
4	200	199.79			
5	200	199.67			
I1	100	99.72	99.85	0.078	0.22
2	100	99.91			
3	100	99.89			
4	100	99.87			
5	100	99.90			
J1	26.02	25.95	25.95	0.0340	0.86
2	26.02	25.89			
3	26.02	26.00			
4	26.02	25.95			
5	26.02	25.93			
6	26.02	25.93			

CONCLUSIONS AND FUTURE PLANS

Before construction of a flow test stand the liquid to be measured must be considered in deciding such alternative methods as volumetric vs gravimetric measurement. Diversion error, although small and perhaps negligible, cannot be overlooked in producing accurate work. The percent uncertainty of a measurement was found to be acceptable. In the lower ranges of flow, the percent uncertainty increased probably due to the calibration of the magnetic flow meter. When the flow meter was recalibrated, the results improved substantially. Future tests will include wastewater effluent although it is suspected that wastewater will have little effect on the volume/time measurements. Due to probable changes in conductance and density and the corrosive nature of wastewater, there may be a small if not negligible effect on the magnetic flow meter.

APPENDIX A

Estimate of Volume/Recorder Time Errors

Two kinds of errors, bias and random, exist in any experiment. The bias error is the difference between the true value and statistical mean. Random error is a measure of the stochastic nature of the experiment. The total error, e, in an experiment for a single sample is the sum of the random and bias errors and can be expressed as:

$$e = B \pm ts\sqrt{1+\frac{1}{n}} \tag{A.1}$$

where B is the bias error

t is student t

s is standard deviation of the sample

n is the sample size.

BIAS ERROR

The bias error consists of three parts: error in the change of the tank volume due to water temperature variation, error in the calibration of the measuring tank, and error in the time measurement. Each of the three errors is discussed as follows:

Bias Error Due to Tank Volume Change

This error due to a water temperature variation can be expressed as:

$$\text{(A.2)} \qquad \frac{q - q_0}{q} = \frac{3\alpha(\theta-\theta_0)}{1+3\alpha(\theta-\theta_0)}$$

where

q = flow rate at water temperature θ

q_0 = flow rate at calibration water temperature θ_0

α = thermal expansion coefficient of measuring tank, $3\times10^{-5}/^{\circ}C$ for fiberglass

If it is assumed that there is a maximum difference of 5°C in water temperature between the time the measuring tank is calibrated and when it is used, then the bias error from equation (A.2) is estimated to be 0.045%.

Bias Error in the Calibration of the Measuring Tank

Since the measuring tank was calibrated by adding 5000 mL from a volumetric flask and noting the rise in the height of water, an error of 1 mL/5000 mL, or 0.02% is assumed as a normal calibration in emptying so large a flask.

Bias Error in the Time Measurement

Since a strip chart recorder is used as a timer by noting the difference in time of the event markers, it is assumed that the bias error is insignificant and can be ignored.

Summary of Bias Errors

The total bias error in term of percentage of the flow rate is 0.045 + 0.02 = 0.065%.

RANDOM ERROR

Random Error Due to Water Level Reading

The random error consists of water level reading, divertor, and strip chart errors. The following equation which relates the flow rate, height and time is used to estimate the random error in a cylindrical tank.

(A.3) $$q = \frac{\pi r^2 h}{T}$$

where r = radius of tank

h = height of liquid level in tank

T = time period to fill the tank

Only the height of the liquid level was taken into consideration in the calibration of the tank volume. The radius of the tank in equation (A.3) can be considered as a constant, and the relative standard deviation of the flow rate can be expressed as:

(A.4)
$$\frac{s}{q} = \sqrt{\left(\frac{dh}{h}\right)^2 + \left(\frac{dT}{T}\right)^2}$$

For a resolution of 1 mm in the height reading at a maximum height of 178 cm, dh/h is equal to 0.056%.

Random Error Due to Diversion

During the time it takes to switch from the sump tank to the measuring tank, there is a possibility of a diversion error. This is a function of the switching time which is assumed not to exceed 5%. Given a valve switching time of 0.5 seconds, 5% water loss during switching time and 30 seconds as the time required to fill the tank to a height of 178 cm at a maximum flow rate, dT/T equals to

$$\frac{0.5 \times 5\% \times 100\%}{30} = 0.083\%.$$

Random Error Due to Use of Strip Chart Recorder

The random error for a strip chart recorder occurs at the highest flowrate and is estimated as:

(A.5) $$\text{chart error} = \frac{Rq}{MV}$$

where R = resolution of the chart, 1/32 in.

M = highest chart speed, 16 in/min.

V = volume of measuring tank, 254 gal.

For a maximum flow rate of 450 gal/min., the chart error is 0.346%.

Summary of Random Errors

The relative standard deviation of the flow rate is $\sqrt{(.0.056)^2 + (0.083)^2 + (0.346)^2} = 0.360\%$. Equation (A.1) can be used to estimate the total error of a single sample. Dividing equation (A.1) by q, the total error can be expressed in percentage of the flow rate as the sum of the bias error, B/q, ± the random error:

(A.6) $$\frac{1}{q}\left[B \pm ts\sqrt{1 + \frac{1}{n}}\right]$$

For n=6 and t=2.571 for a 95% confidence level, the total random error is ± 1%.

APPENDIX B

Systems Errors Using an Electronic Timer

A crystal controlled timer with a temperature stability of ±5 ppm over a temperature range of 0 to 50°C and an accuracy of the crystal of ± 2 ppm was selected for use. This means that the timer has an accuracy of ± 0.00055%.

Using the information given in Appendix A, the overall error is calculated below:

Bias Error Calculation

Temperature (tank expansion) error = 0.045%.

Calibration error = 0.02%.

Bias error = 0.02 + 0.045 = 0.065%.

Random Error Calculation

The relative standard deviation is

$$\sqrt{(0.056)^2 + (0.083)^2 + (5.5\text{x}10^{-4})^2} = 0.1\%.$$

For n=6 and t = 2.571 for a 95% confidence level, the total random error can be calculated by using equation (A.6) and is ± 0.278%.

APPENDIX C

Estimate of Weight/Time Errors

The equation

(C.1) $$q = \frac{W}{\rho g T}$$

defines the flow rate into the measuring tank in terms of weight.

where

W = measured weight for a period to time t.

ρ = apparent density, $(\rho_w - \rho_a)$.

ρ_w = density of water

ρ_a = density of air

g = acceleration due to gravity

T = period during which water is collected.

The error involved in measuring by weight is defined as:

(C.2) $$\frac{dq}{q} = \frac{dW}{W} - \frac{dT}{T} - \frac{d\rho}{\rho}$$

and the coefficient of variation is:

(C.3) $$\frac{s}{q} = \sqrt{\left(\frac{dW}{W}\right)^2 + \left(\frac{dT}{T}\right)^2 + \left(\frac{d\rho}{\rho}\right)^2}$$

A survey of balances showed that the best accuracy was about a pound in 2500 lbs. or 0.04%. Using an electronic timer, an error of about ± 5.5 x 10^{-4}% can be expected for time measurements.

BIAS ERROR

The bias error for the scale and electronic timer is assumed to be insignificant and therefore will be ignored in the error analysis.

RANDOM ERROR

The random error was estimated using equation (C.3). For measuring the density, it was assumed that an error of as much as 2°F can be made in estimating densities. This error was calculated to be 0.018% by considering the densities of water at 60 and 62°F.

$$\frac{dp}{P} = \frac{p(60^\circ) - p(62^\circ)}{P(60^\circ)} = \frac{62.3663 - 62.3549}{62.36} = 0.018\%$$

In the case of random error, the term $\frac{dT}{T}$ becomes the diversion error which is 0.083% as described in Appendix A. Therefore, the coefficient of variation can be calculated using equation (C.3).

$$\frac{s}{q} = \sqrt{(.04\%)^2 + (0.083\%)^2 + (0.018\%)^2} = 0.0939\%$$

Using n = 6 and the student's t = 2.571 for a 95% confidence statement, the overall error is ± 0.261%.

APPENDIX D
DERIVATION OF DIVERSION ERROR EQUATION

$$(D.1)\quad Q_V = \frac{V}{T+E} = \frac{V}{T}\left[\frac{1}{1+\frac{E}{T}}\right]$$

where V is volume of water collected and E/T is the diversion error ratio.

$$(D.2)\quad q_v = \frac{\sum_{i=1}^{N} V1_i}{\sum_{i=1}^{N} (T1_i + E)} = \frac{\sum_{i=1}^{N} V1_i}{\sum_{i=1}^{N} T1_i}\left[\frac{1}{1+\frac{\sum_{i=1}^{N} NE}{\sum_{i=1}^{N} T1_i}}\right]$$

The ratio of equations (D.1) and (D.2) is

$$(D.3)\quad \frac{Q_V}{q_v} = \frac{\frac{V}{T}\left[\frac{1}{1+\frac{E}{T}}\right]}{\frac{V^*}{T^*}\left[\frac{1}{1+\frac{NE}{T^*}}\right]}$$

where: $T^* = \sum_{i=1}^{N} T1_i$ and $V^* = \sum_{i=1}^{N} V1_i$

The equations relating flows as measured by the magnetic flow meter are:

$$(D.4)\quad Q_m = \frac{V}{T} \quad \text{and} \quad (D.5)\quad q_m = \frac{V^*}{T^*}$$

substituting equations (D.4) and (D.5) into (D.3) yields,

$$(D.6)\quad \frac{Qv}{qv} = \frac{Qm}{qm}\,\frac{\left[\frac{1}{1+\frac{E}{T}}\right]}{\left[\frac{1}{1+\frac{NE}{T^*}}\right]}$$

which simplifies to (D.7)

(D.7) $$E/T = \frac{\frac{Q_v}{q_v}\frac{q_m}{Q_m} - 1}{\frac{NV}{V^*}\frac{q_m}{Q_m} - \frac{Q_v}{q_v}\frac{q_m}{Q_m}}$$

APPENDIX E

The energy losses in the piping system of the flow test stand arise from the following losses: a) 63.5 feet of 3-inch straight pipe, b) 7.5 feet of 4-inch straight pipe, c) 90˚ bend of 4-inch pipe, d) the nine 90˚ bends of 3-inch pipe, e) the TEE which is connected to the pressure relief valve which acts as a safety for the pump, f) the control valve, g) the ball valves which are used in the diversion, h) 3-to-4 inch enlargement and i) a venturi which is used as a test meter.

The Darcy equation is basically used in making most of these calculations. The headloss for a straight pipe is:

$$h_L = \left(f \frac{L}{D} \right) \frac{U^2}{2g}$$

where: f = friction factor (0.019 is used in all cases)

L = length of pipe

D = diameter of pipe

U = velocity

g = acceleration due to gravity, 32.2 ft/sec^2

For bends, TEEs and valves, the Darcy equation is slightly modified to:

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For bends, TEEs and valves, the Darcy equation is slightly modified to:

$$h_L = K \frac{U^2}{2g}$$

where h = the headloss per TEE or bend

K = 12f for 3-inch bends

= 12f for 4-inch bends

= 20f for TEE

= 3f for 3 inch Ball valve

= 3.96 for control value at 550 gal/min based on manufacturer's specifications.

The suction headloss for the pump is determined from the pump performance curves. The venturi headloss is given as 3 feet in its specifications. All the headlosses were calculated and listed in Table 3.

Nomenclature

B	= Bias error
D	= Diameter of pipe
e	= Total bias and random errors
E	= Diversion error
f	= Friction factor
g	= Acceleration due to gravity
h	= Height of measuring tank
h_L	= Headloss in feet of water
L	= Length of pipe
m	= Degrees of freedom
M	= Chart speed
n	= Number of samples

N = Number of diversions during one filling of tank

p = Apparent density

p_w = Density of water

p_a = Density of air

q = Flowrate

q_m = Magnetic flowmeter reading

q_v = Flowrate as measured by the volume/time method during diversion test

Q_m = Magnetic flowmeter reading during long time collection

Q_v = Volume/time measurement during long collection time

r = Radius of measuring tank

R = Resolution of strip chart recorder

s = Standard deviation

t = Student's t

$t_{m,0.025}$ = Student's t at m and 95% confidence

T = Time

U = Velocity

V = Volume of measuring tank

$\overline{X}$ = Mean

W = Measured weight

α = Thermal expansion coefficient of measuring tank, $3 \times 10^{-5}/^{\circ}C$ for fiberglass

θ = Water temperature

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